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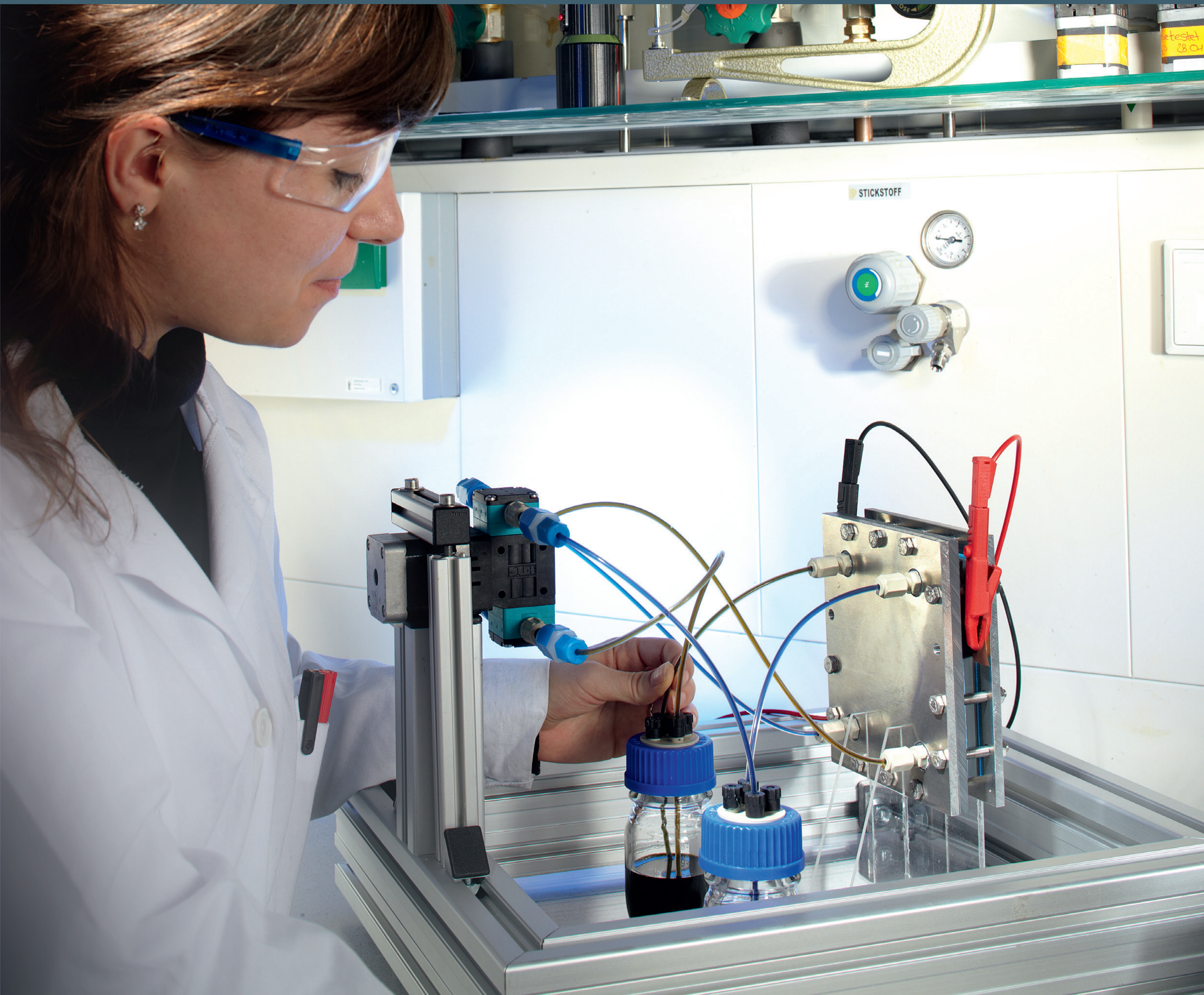
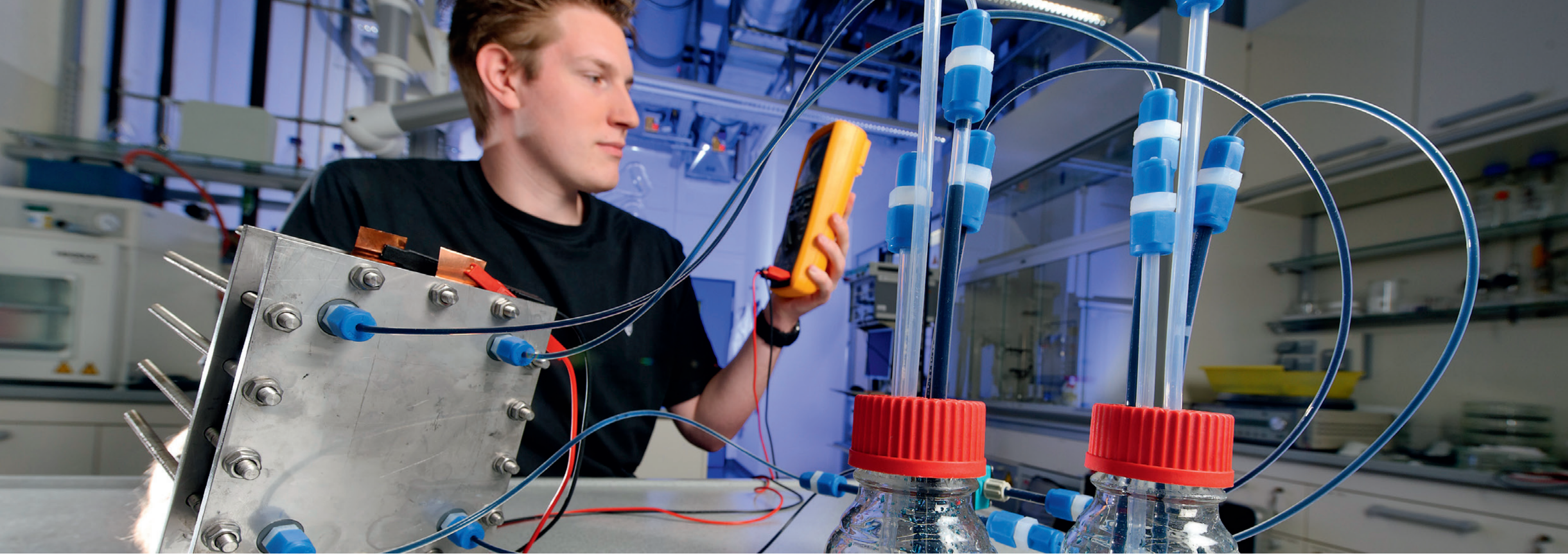
FRAUNHOFER INSTITUTE FOR CHEMICAL TECHNOLOGY ICT

REDOX-FLOW BATTERY



REDOX-FLOW BATTERY



REDOX-FLOW BATTERY

Redox-flow batteries are efficient and have a longer service life than conventional batteries. As the energy is stored in external tanks, the battery capacity can be scaled independently of the rated battery power.

Redox-flow batteries are electrochemical energy storage devices based on a liquid storage medium. Energy conversion is carried out in electrochemical cells similar to fuel cells. Most redox-flow batteries have an energy density comparable to that of lead-acid batteries, but a significantly longer lifespan.

In the electrochemical cell, electrolyte solutions flow through the half-cell compartments of the plus and minus pole. To prevent the two solutions from mixing, the half-cells are separated by an ion-conducting or semi-permeable membrane. The potential difference of the electrolytes generates a voltage at the electrodes. If the electric circuit is closed, an electrochemical reaction sets in and electricity begins to flow (compare fig. 1). In order to charge the electrolytes, an external voltage is applied to the cell, and the reaction in the half-cells is initiated in the opposite direction. This reaction charges the electrolyte.

As in fuel cells, individual cells can be combined in series to create a so-called "cell stack". The stacks themselves are then connected fluidically and electrically to batteries.

As redox-flow batteries are based on external energy storage media, the power and capacity of the battery can be scaled independently: the volume of electrolyte determines the battery capacity (the "quantity" of energy stored), while the surface area and number of cells determines the power. The storage of electrolyte in separate tanks means that virtually no self-discharge occurs when the system is not in operation. This makes the technology suitable for application in uninterrupted power supply. A further field of application is the storage of energy from renewable sources, such as solar and wind.

Fig.1: Schematic diagram of the processes within a redox-flow system

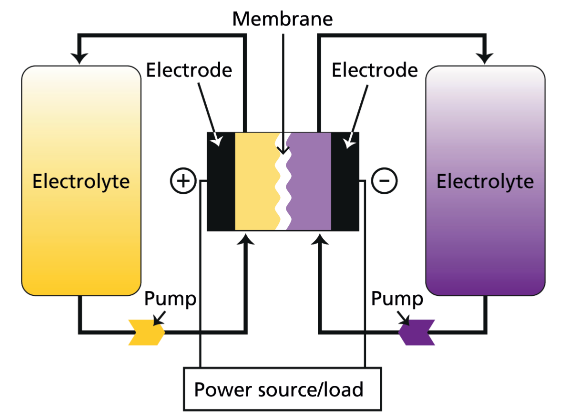
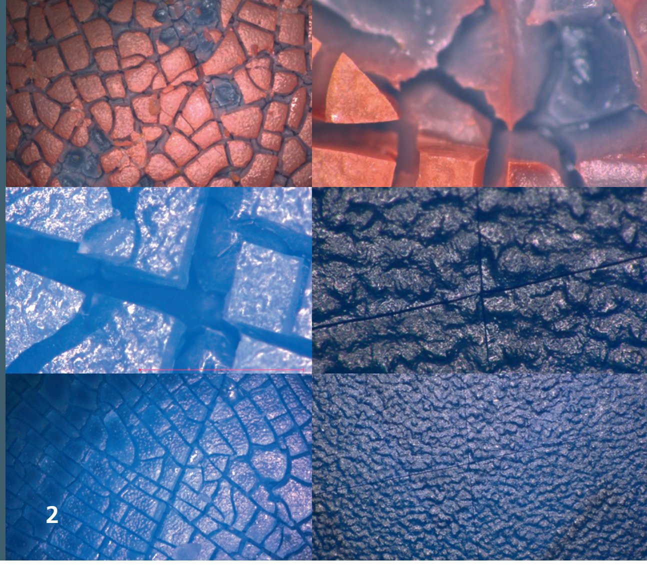


PHOTO LEFT

RFB test rig.



MATERIAL DEVELOPMENT AND CHARACTERIZATION

At the Fraunhofer Institute for Chemical Technology ICT, materials for redox-flow batteries are investigated and further developed. This includes the characterization of battery materials, investigations into long-term stability and the development of corrosion-stable bipolar plates.

An important challenge in the field of redox-flow batteries is to reduce the cost of the functional materials in the stack. In order to achieve a significant cost reduction while at the same time optimizing the electrochemistry of the system, Fraunhofer ICT continuously investigates new materials in terms of their potential for application in redox-flow batteries. For this purpose individual cells are set up and characterized using electrochemical methods (e.g. impedance spectroscopy and charge/discharge tests). In the cell test, materials such as membranes, porous and textile electrodes, materials for bipolar plates, alternative cell geometries and novel electrolyte formulations are tested regarding their performance and efficiency. Single cells can also be equipped with reference electrodes, so that the properties of the half-cells can be examined separately. In addition, various flow-through cells are used to conduct VIS/NIR and RAMAN spectroscopic in-situ measurements on electrolytes at different states of charge. Test cells for novel redox-flow battery systems have been developed and constructed at the institute since 2006.

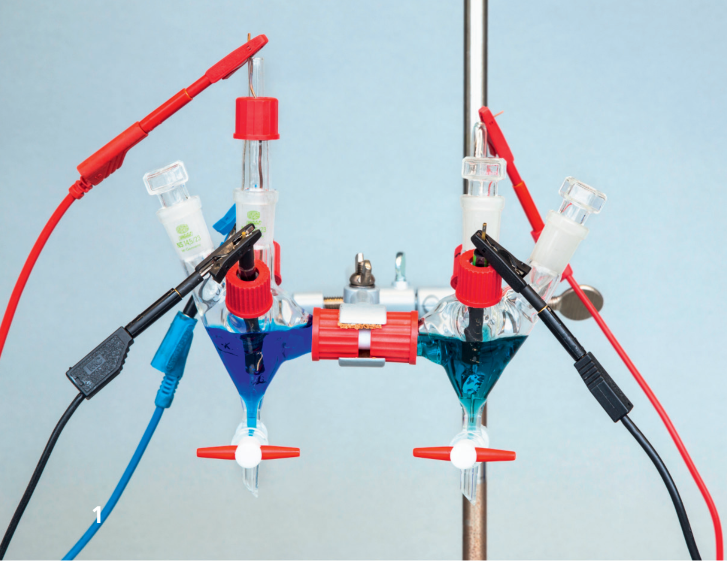
Bipolar plates play a decisive role as internal current collectors within redox-flow batteries. The development of cost-effective, mass-producible, electrically highly conductive and chemically stable bipolar plates made from carbon polymer composites is essential for the commercial breakthrough of redox-flow batteries. At Fraunhofer ICT materials can be produced from the compound to the finished plate or foil. Using injection molding, bipolar plates with dimensions of up to 800 x 250 x 3 mm can be produced.

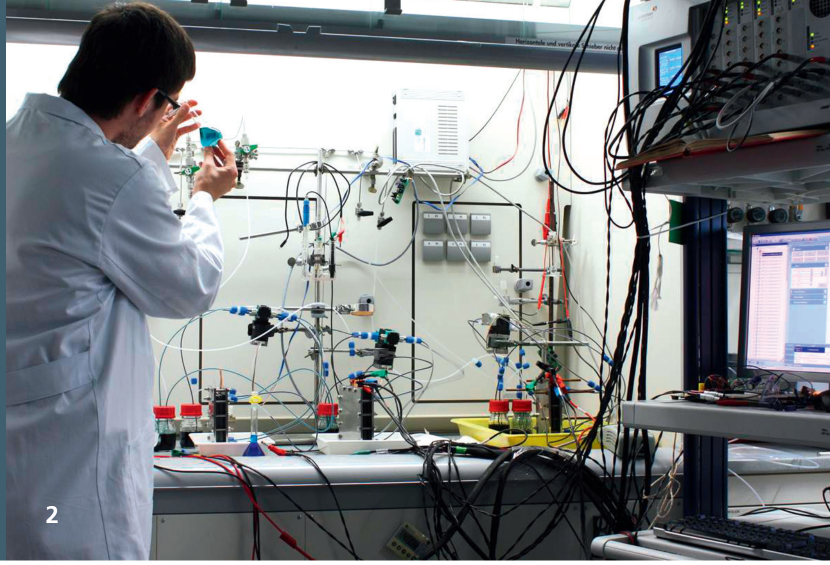
Our offer

- The testing of materials such as membranes, electrodes, bipolar plates or electrolyte formulations in a cell test (individual cells / galvanostatic charge and discharge cycles / at custom temperature conditions or in a climate chamber)
- Testing of the materials listed above according to customer specifications (e.g. protocols or cycles causing artificial aging)
- Long-term measurements in single cells
- Development of test cells with connected in-situ or online measurement devices or reference cells for spectroscopic measurements according to customer requirements

1 *RFB cell test.*

2 *Light microscope image of degraded gasket material.*





REDOX CHEMISTRY

At Fraunhofer ICT electrolyte formulations for all-vanadium redox-flow batteries are developed and optimized. In addition, formulations for other flow battery systems are investigated, electrochemically tested and characterized in a cell test. Particular attention is paid to electrolytes for bromine-based and organic redox-flow batteries, as well as vanadium-air systems.

In all-vanadium redox-flow batteries (VRFBs) energy is stored in chemical form, using the different oxidation states of dissolved vanadium salt in the electrolyte. Most VRFB electrolytes are based on sulfuric acid solutions of vanadium sulfates. An important feature of this system is the complex chemistry of pentavalent vanadium, which tends towards irreversible condensation at temperatures above 40°C. This temperature threshold limits the application range of the system. To increase the range of operating temperatures and improve the efficiency and power density, at Fraunhofer ICT new electrolyte formulations for vanadium electrolytes are under investigation.

The electrode kinetics of the electrolyte solutions are investigated using voltammetry. Based on battery charging cycles in standardized test cells, the performance and efficiency of the electrolytes can be precisely characterized.

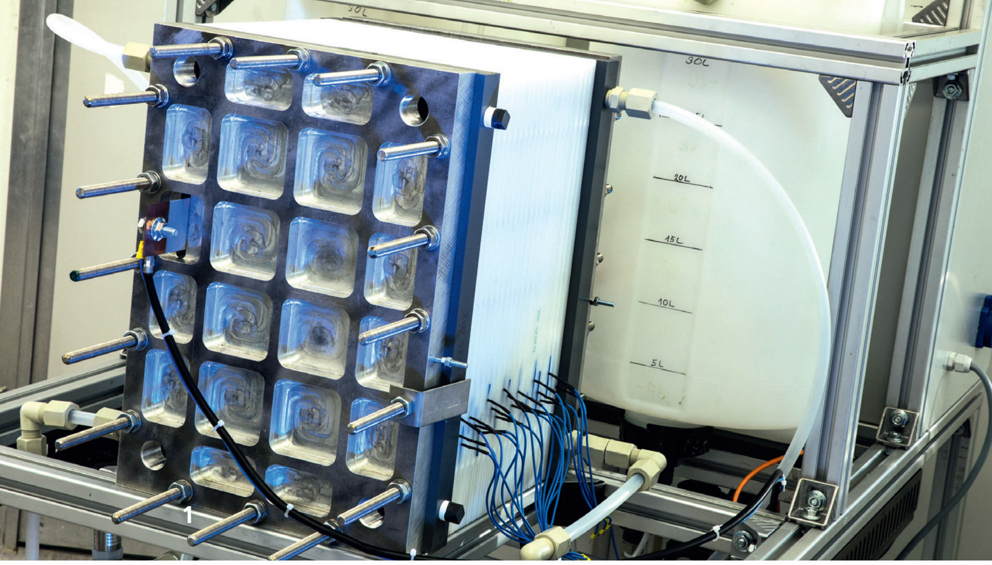
In addition, commercial redox-flow battery systems, as well as those in the research stage, are electrochemically characterized in half-cell tests. Due to the high electrode potential and the easy availability of the starting material, many redox-flow batteries are based on the bromine/bromide redox couple. However, high bromine concentrations can only be achieved in the aqueous electrolyte solutions when polybromides or polyhalides (Br_3^-, Br_5^-, $ClBr_2^-$) are formed. In this context we are focusing on new complexing agents to produce bromine-electrolyte solutions with higher energy densities and increased safety.

Our offer

- Development or improvement of electrolyte formulations by electrochemical and physicochemical analyses
- Voltammetric investigations (stationary or rotating electrodes) on model electrolytes according to customer requirements
- Production of pure vanadium (II) sulfate - hydrate and vanadium (III) sulfate - hydrate salts for model electrolytes
- Electrochemical investigation of new electrode materials for application in VRFBs (voltammetry, impedance spectroscopy, cell tests)
- Spectro-electrochemical investigations of glass, carbon or customized materials
- Generation of customer-specific specifications for electrolyte solutions

1 *Electrochemical measurement cell with separate half-cells.*

2 *Test bench for single cell measurements.*



STACK DEVELOPMENT AND BATTERY SYSTEMS

From the construction of prototype batteries to the development of industrial production processes for battery stacks, Fraunhofer ICT covers every stage in battery production. The institute can also carry out tests to certify flow batteries from the stack up to entire battery systems.

Prototype development and tests on cell stacks

The stack is a core component of redox-flow batteries. Together with the electrolyte solutions, its power output largely determines the efficiency and cost of the electricity storage device. Stacks are complex electrochemical flow reactors, in which a low pressure drop, an even flow distribution, a homogeneous electrochemical reaction as well as low internal resistance have to be achieved. However, depending on the requirements of the battery chemistry applied, stacks can differ considerably from each other.

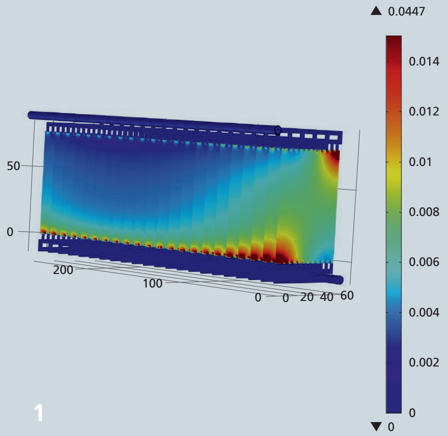
Besides technical design, cell and stack geometries can be investigated using fluid simulations and electrochemical models, to determine their suitability and potential optimizations. The development of cell prototypes, their testing and subsequent scale-up to the finished stack is carried out using various manufacturing technologies suited to mass production, and is adjusted to industrial production processes.

System tests

Fraunhofer ICT has developed and constructed its own test rigs to investigate RFB stacks. The test rigs have comprehensive safety features and can be operated fully automatically. The simple, modular construction and control via an industrial programmable logic controller (PLC) means that the test rigs require little maintenance.

For battery testing according to different battery standards, stress tests and long-duration studies, battery test systems with different performance categories are available:
- All sizes up to 60 kW charge/discharge performance
- Individual cell measurement module with 64 single-channel measurements up to 0-5 V each.

1 *RFB stack with side connectors for single cell measurements.*
2 *Redox-flow stack test rig for power outputs up to 4 kW.*



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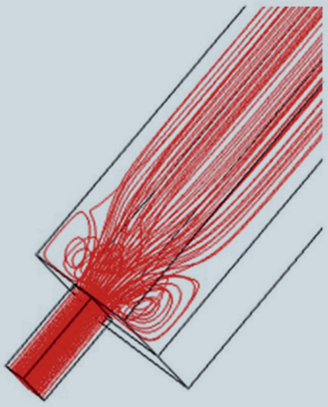

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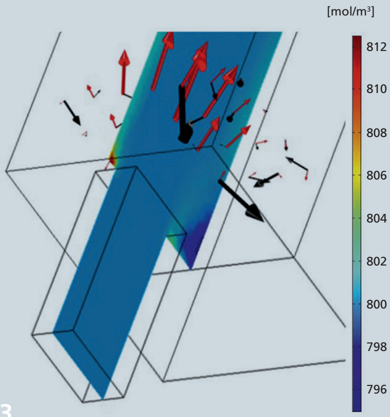

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MODELING AND SIMULATION

At Fraunhofer ICT fluidic, thermal and electrochemical models of redox-flow batteries are used to gain a better understanding of battery behavior during operation. New sensor technologies such as spatially resolved current density measurements provide insights into the working battery. On a system level we offer storage designs involving a range of technologies, and technical-economic investigations of microgrids.

Fluid simulations

Inserting measuring probes into working batteries is difficult. For this reason, it is particularly important to model redox-flow cells in the design phase, and to use these results to simulate virtual batteries. Using these battery simulations, the characteristics of redox-flow batteries can be investigated and used to evaluate different battery concepts, from individual cells up to large, stationary energy storage devices.

The performance of a redox-flow cell depends most significantly on the geometric configuration of the cell, the electrolyte flow and also the material used. The first step in the modeling is the CAD representation of the cell. In the model, the flow simulation (CFD) is linked to the physicochemical simulation of the electrode processes, and enables the spatial representation of local electrochemical phenomena in the cell.

In a single stack, or in a system consisting of several connected stacks, the performance is also influenced by phenomena arising from the fluidic as well as the electric interconnection of electrochemical cells, such as shunt current losses or unequal flow distributions. The abstract modeling of stacks enables these effects to be evaluated, and potential improvements can be identified.

Storage design

Stationary energy storage devices are increasingly used in decentralized systems. Using a system simulation for microgrids, Fraunhofer ICT optimizes the operating strategy, the selection of storage technologies and the dimensioning of storage devices and renewable energy generators. This process takes account of the technical and economic framework as well as the planned location of use. The simulation is based on consumer load profiles and weather-dependent data on electricity generation from renewable energy sources.

1 *Simulation of the flow velocity in an RFB stack*
2 *Lines of flow in a CFD simulation of a single entry channel*
3 *Simulation of transport processes in a single entry channel*

REDOX-FLOW BATTERY

Fraunhofer Institute for Chemical Technology ICT

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